Part 3: Your Family Tree

Chapter 10: Family Trees

1. A standard tree
   a. The simplest family tree starts with one person. Above that person is drawn a T, with the mother and father shown on the two sides of that T. The parents will have Ts above them, showing their parents (who are, of course, the first person’s grandparents), and so on. A more complex family tree will show siblings as well, along, perhaps, with adopted children.
   b. We will be primarily interested in your biological family tree. It will show who your biological parents were, who theirs were, and so on. Thus, if you were adopted, we will not show the man and woman who adopted you; likewise if you were accidentally switched at birth, we will not show the man and woman you accidentally ended up with. Along similar lines, your biological father might or might not be the man to whom your biological mother was married; it depends on how adventurous she was.
      i. Notice that the identities of the people appearing on a biological family tree cannot be known for certain. This would be a problem if our goal were to actually produce a biological tree for someone, but this is not our goal. Our goal here instead is to use biological family trees to help us explore a number of concepts.
   c. Another tree you can construct is your paternal family tree. To construct such a tree, you simply erase all women from your biological family tree. What you are left with is a tree with you at the bottom, your father above you, your father’s father above him, then your father’s father’s father, and so on. Notice that even women can construct their paternal family tree.
      i. This sort of tree would have been of particular interest in the past, when power and property were held by a father and passed to his son. What these people were doing was tracing their lineage or bloodline, and the appearance of “line” in these terms is not an accident: what you end up with is not a tree that branches, but a vertical line: it would resemble a bamboo stalk, rather than an elm.
      ii. One can, of course, construct a maternal family tree instead of a paternal family tree.

2. Exploding trees
   a. My own ancestry research
      i. I got an offer to join Ancestry.com and did some basic research on my own ancestry. I discovered that in 1940 (according to the census of that year), my mother worked 48 hours per week as a hospital receptionist and had an annual income of $1427. This works out to about sixty cents an hour—about $10 an hour in today’s dollars. I also discovered that her father had worked, for a time, as a lumber piler in a sawmill, that he was the eighth of ten children, and that his family would probably have been even bigger had his father not died.
      ii. My biggest discovery, though, was the realization of how, with each step back in your ancestry, the job gets at least twice as hard as it previously was. For one thing, the records you have access to tend to get sketchier, the further back you go. More important, though, for each level you go back in your family tree, there will be twice as many ancestors to investigate than there were at the previous level.
In most undertakings, the longer you devote yourself to a task, the closer to completion you will be. This is not the case with ancestral research. The further back you go, the harder it becomes to continue.

b. Family trees grow at an exponential rate, doubling in size each generation. You have two parents, four grandparents, eight great-grandparents, and so on. Do your family tree back 10 generations, and you have $2^{10}$, which is equal to 1024, direct ancestors. Let us round this off to an even thousand. Go back another ten generations, and each of your thousand direct ancestors will himself or herself have a thousand direct ancestors, meaning that you will have a thousand times a thousand, or a million direct ancestors. Similar logic tells you that ten generations before that (in other words, thirty generations back) you will have a billion direct ancestors. And go back ten generations before that (to forty generations ago) and you will have a trillion direct ancestors. It is an ancestral population explosion!

c. But realize that if we allow 25 years, on average, per generation—which is a reasonable length of time to use, given that in the past people married young and didn’t have effective means of birth control—we come to the conclusion that only 1000 years ago (= 40 generations × 25 years/generation), you have a trillion direct ancestors. But there is a problem with this number. In the year, 1000 A.D., there weren’t a trillion people on earth! Indeed, it has been estimated that in all human history—in, that is, the time our species has existed—only about 100 billion people have ever lived. [http://www.prb.org/Articles/2002/HowManyPeopleHaveEverLivedonEarth.aspx] In other words, there don’t appear to be enough people to populate your family tree. Let us call this the family tree paradox. We will examine it in more detail in a moment.

d. If you attempted to construct an actual family tree for yourself, going back to the year 1000 A.D., you would encounter two problems.

i. The first is identifying the people who occupy the positions on this tree. This would be hard enough if you were constructing a tree for your “officially-recognized” ancestors; it is impossible, though, if you are interested in your biological family tree. Can you really be sure that a female ancestor forty generations back—or even one generation back!—didn’t fool around?

ii. But even if we could, miraculously, determine the identities of our ancestors 1000 years ago, we could never physically construct a diagram of that tree. As we have seen, the tree would have to include the trillion direct ancestors you had 40 generations ago. If we allowed a mere one centimeter per ancestor at the top of our tree, the paper on which we drew the tree would have to be 1 trillion centimeters wide, which works out to more than 6 million miles wide. (To put things into scale, the moon is 240,000 miles away.) Is there even enough paper on earth to do this?

(1) Ancestry research companies are happy, after selling you access to ancestry records, to sell you software to keep track of what you find. Such software quickly becomes necessary!

3. The race question

a. This “exploding tree” phenomenon is bad news for anyone who is obsessed with racial or ethnic “purity.” To see why, suppose someone asserts that if you have even one drop of X blood in you—where X is the racial or ethnic group they dislike—then you are an X yourself. To establish that he is not himself an X, this person will have to demonstrate that not one of his thousand direct ancestors of 250 years ago was an X. This task will not be easy to accomplish, and if he succeeds in accomplishing it, we can go on to ask him about his trillion direct ancestors of 1000 years ago.
b. This line of thinking also raises an important question about what determines an individual’s race. Suppose we offer a **recursive definition of race**. Suppose, in particular, we assert that if both your parents are black, then you are black as well. Many people would accept this definition. Realize, however, that if we accept it, we have no choice but to conclude that we are all black!

i. If, after all, we trace our family tree back 100,000 years, we will find that all of our direct ancestors lived in Africa. According to scientists, this is where the species Homo sapiens came into existence. Some of our ancestors remained there, but others headed for Europe and Asia about 60,000 years ago.

ii. Scientists are confident that these ancestors would have been dark skinned. After all, to be light-skinned and clothes-less in the African environment would be a recipe for skin cancer. Bottom line: trace back your family tree 100,000 years, and you will find that your ancestors were all black.

(1) The current theory is that light-skinned people arose only when some members of our species moved to higher latitudes in Europe. There was less sunlight. They also would have been more likely to wear clothing. (It was cooler, after all, and they would finally have invented the technology necessary to construct form-fitting clothes—they would, in other words, have invented the needle.) Under such circumstances dark-skinned people would be at a disadvantage, since they would be vitamin-D deficient. (When our skin is exposed to sunlight, our bodies make vitamin D, but the melanin that makes skin dark interferes with this process.) Light-skinned people would be more likely to survive and reproduce.

c. But if all of your ancestors 100,000 years ago were black, then according to the above recursive definition of race, so were their offspring, meaning that their offspring’s offspring were black as well, and so on, down to the present time. Conclusion: we are all black! More specifically, we are all blacks of African ancestry.

d. A side trip: If a black person and a white person have a baby, we can argue about the race of that baby. Is it black? White? Biracial? And oh, by the way, what race is Barack Obama? He says he is black, but do we have to take his word for it? How are such things determined?

i. A case can be made that we are all bi-racial. And if we are asked, on a form, to fill in our race, perhaps the most correct answer is “human”: We all belong to the human race.

4. The solution to the family-tree paradox

a. Family trees, as I have said, generate a profound paradox: as you go back in time, the number of ancestors you need to populate your tree grows larger, but the number of humans available to populate that tree (in other words, the number of people who then existed) gets smaller. At some point, there simply aren’t enough people around for you to populate your tree.

b. This paradox, though, is easy enough to resolve. It exists only because we assume that each position in your family tree will be occupied by a **different** person. What you find, though, is that as you go back in your family history, people start occupying multiple positions on your family tree. Allow me to explain.

i. It is possible, to begin with, for a person to appear in more than one spot in a given generation. Suppose, in the simplest possible (albeit morally disturbing) case, that you marry a brother or sister, and have a child. This child, when he constructs his family tree, will find that his maternal grandparents are the same as his paternal grandparents (since his mother’s parents will be the same as his father’s parents). Not only that, but going back before that, the two sides of his family tree will be mirror images of each other. It will therefore require “only” half a trillion people (at most) to populate his family tree back 40
generations. And if some of his ancestors also married their siblings, the number of people required by the tree will shrink even more.

(1) The basic principle: if a person appears in multiple places on a family tree, then the branches above those spots will all be identical, meaning that the ancestors of the multiply-appearing individual will also be multiply-appearing individuals.

ii. It is also possible for a person to appear in two generations of a family tree. The simplest case is when a father has a child with his daughter. Suppose they have a son. When this son constructs his family tree, he will find that his father is also his maternal grandfather.

iii. Depending on the reproductive choices your ancestors made, even a basic family tree can be quite complex. Consider, by way of illustration, the family tree of Debbie Palmer, who grew up in a fundamentalist Mormon community, in which plural marriages were the norm, rather than the exception. When she presented author Jon Krakauer with her own family tree, he was perplexed. The document she presented him with, he says, appeared, at first glance, “to map out the intricacies of some massive engineering project—a nuclear power plant, perhaps.” She walked him through the intricacies of the diagram and explained to him, among other things, that because she had married the father of the stepmother to her stepmother, she was in fact step-grandmother to herself.[Under the Banner of God, p. 29]

c. Marriage between cousins

i. Some terminology: Siblings have parents in common. First cousins have grandparents, but not parents, in common. And second cousins have great-grandparents, but not grandparents, in common. Stated differently, A and B are second cousins if they are the offspring of first cousins, and C and D are first cousins if they are the offspring of siblings.

ii. Suppose first cousins marry and have children. When these children construct their family tree, they will find that they have grandparents in common. This will result in considerable duplication in their family tree, and thereby reduce the number of people necessary to populate it.

iii. We might think that marriage of cousins is uncommon, but this is not the case.

(1) In the past, when people lived in villages and were unlikely to travel very far, cousin-marriage was common. In many ethnic groups, by the way, marriages of first cousins are fairly common. Likewise, members of religious groups are like to marry within the faith, even though this means marrying a relative.

(2) Even among royalty we find relatives marrying. Consider the British royal family, Queen Elizabeth and her husband Prince Philip. They are, according to one researcher, “second cousins once removed (through King Christian IX of Denmark and his wife Louise), third cousins (through Queen Victoria of England and her husband Albert), and fourth cousins (through Duke Ludwig Friedrich Alexander of Württemberg and his wife Henriette).”[ David Eppstein, “Finding Common Ancestors and Disjoint Paths in DAGs”]

(3) Thus, according to British social theorist Robin Fox, “If we could only get into God's memory, we would find that eighty per cent of the world's marriages have been with at least second cousins.” [Quoted in Shouratoff, “The Mountain of Names”]

iv. Even today, marriage between relatives isn’t uncommon. Marriage of second cousins, for example, is legal in every state, and marriage of first cousins is legal in seventeen states, and, if certain conditions are met, in seven others. And no, the states in which marriage of first cousins is legal are not the states you might expect. Such marriages are not legal in Kentucky and Mississippi, for example. Nor are they legal in Utah. But they are legal in California and New York.[http://www.cousincouples.com/?page=states]
d. Even if you marry a complete stranger, it is highly likely that if you start constructing your family trees, you will start finding ancestors in common. And of course, the ancestors of these ancestors in common will also be ancestors in common. It is a good bet that this will happen if you trace back ten generations, and it is almost a sure thing if you trace back thirty.

i. Here is how one writer describes the situation: “Each time cousins marry, a duplication will occur in the pedigrees of their descendants because as cousins they already occupy a slot in them. The farther back one traces any person's genealogy, the greater the rate of duplication, until finally, when cousin intermarriage begins to predominate, the shape of the pedigree, in theory, stops expanding, and begins to narrow. Each person's complete family tree, in other words, is shaped more or less like a diamond. In the beginning, it expands upward from the person in an inverted triangle. At some point, hundreds of years back, the rate of expansion reaches its maximum and the pedigree starts to narrow, eventually coming to a point at a theoretical first couple.” [Alex Shoumatoff, “Mountain of Names”]
Chapter 11: Your Blue Blood

1. Trees of descendants
   a. We have explored family trees, along with the family-tree paradox and its solution. But there is another way to look at things. A family tree can also be called a tree of ancestors. Instead of constructing trees of ancestors we can construct trees of descendants. These trees list all the descendants of some historical figure.
   b. Such a tree will look like an “inverted” family tree. One might also say that instead of looking like a tree, it will look like the root system of a tree. At the top, it will list a historical person, say George Washington. Below him, it will list Washington’s biological offspring. Below them, it will list their biological offspring, and so forth. For one version of the actual tree, see http://www.wessyngton.com/blog/wp-content/uploads/2009/05/washington-family-tree.jpg
   c. Realize that Martha Washington needn’t have the same tree of descendants as George does. This will be the case if she had children by a man other than George. If, however, George has all of his offspring with Martha, and vice versa, their trees of descendants will be identical.
   d. Notice, too, that although in a tree of ancestors, each person has two people branching out above him—a mother and father—in trees of descendants, the “roots” below a person can have any number of people. If a man has three offspring (perhaps with various women), he will have three people directly below him in his tree of descendants. If he has no offspring, he will have nothing below him: he will represent a “dead end” in the tree of descendants.
   e. And one last thing: realize that although one person can appear in several different positions on your tree of ancestors, a given individual can appear at most once on your tree of descendants. Suppose, for example, that A and B have C as their daughter, and that A and C subsequently have D as a son. D’s tree of ancestors will be a bit strange, with A appearing as both his father and maternal grandfather. If we construct A’s tree of descendants, though, (and leave B out of things) it will be straightforward. Directly under him will be both C and D, with no difference in how they are represented.
   f. The people in this room will all have, as we have seen, very complex trees of ancestors. Because you are relatively young, though, your trees of descendants will be quite simple.

2. From two to many
   a. Notice that whereas trees of ancestors necessarily get “wider” the higher up we go, trees of descendants typically get wider the farther down we go. This growth can be quite dramatic. To see why, consider the hypothetical case of Robinson and Roberta Crusoe. After what was supposed to be a three-hour tour, they get stranded on an island.
      i. It is possible for the population of the island to remain at two.
         (1) Suppose, for example, that Robinson and Roberta have two offspring who marry and have two offspring, who in turn marry and have two offspring, and so on, for ten generations. (For this to happen, of course, the two offspring would have to be brother and sister, and the genetic consequences of all this inbreeding cannot be so extensive that it prevents them from having and raising offspring; but let us, to keep things simple, ignore these factors.) At the end of these ten generations, there will, in theory, be two people on the island.
         (2) Notice that Robinson Crusoe’s tree of descendants will nevertheless have grown hugely, but that as we move down the tree, the same persons will start appearing in multiple positions. This is the “mirror image” of what happens in trees of ancestry.
      ii. It is also possible that the population of the island will explode. Suppose, for example, that
Robinson and Roberta have four children (two sons and two daughters) who pair up, with each couple having four children, and so on. At the end of ten generations, there will, in theory, be about a thousand people on the island.

iii. When these thousand people construct their trees of ancestry, they will find that ten generations back, they have nearly a thousand ancestors. The striking thing is Robinson will fill half of these thousand ancestor positions, and Roberta will fill the other half.

iv. This scenario may sound hypothetical, but realize that it is how many remote islands get populated with birds and other animals. Two members of a species, one male and one female, are blown onto, drift onto, or are set (by sailors) onto an island. A hundred years later, that island might be overrun by animals of that species.

v. If you believe in the Biblical story of creation, by the way, you may not know who fills most of the positions in your family tree of ancestry. You probably won’t, in particular, be able to name all of the thousand individuals who appear ten generations back. But you will be able to state, with perfect certainty, who will appear in the highest level of the tree: it will be Adam and Eve, over and over. Furthermore, you will necessarily be in Adam and Eve’s tree of descendants.

(1) A question: who did Abel and Cain, the sons of Adam and Eve marry? For an interesting discussion of this question, see:

3. The kings and queens in your family tree
   a. How likely is it that you will find royalty in your tree of ancestors? Surprisingly likely. This is a consequence of two facts: as you go back in time, your family tree grows very fast, but as you go back in time, the population available to fill that tree gets smaller. It therefore becomes likely that kings and queens will be “recruited” to fill positions on your family tree.
   b. Another way to think of this is to keep in mind that trees of descendants get larger with the passage of time. It wouldn’t be hard for someone who lived five hundred years ago—let us refer to him as X—to have a tree of descendants that at present has a million individuals on it. (Five-hundred years represents perhaps twenty generations of descendants; if each of these descendants has two offspring, who in turn have two offspring, the end result will be $2^{20}$ offspring, about a million individuals.) When each of these individuals does their family tree, X will show up. And if X was, in his time, particularly prolific, there might be many more than a million currently-living individuals in his tree of descendants. Along these lines, it is helpful to keep in mind that there are sultans and kings who have fathered more than a hundred children. (And in modern times, there are sperm donors who have accomplished this same feat.)
   c. In the words of science writer Guy Murchie, “It is virtually certain... that you are a direct descendant of Muhammad and every fertile predecessor of his, including Krishna, Confucius, Abraham, Buddha, Caesar, Ishmael and Judas Iscariot.” He adds that if you investigate your family tree, you are also likely to discover historically famous criminals.[Quoted in Alex Shoumatoff, Mountain of Names]
Chapter 12: Your Extended Family Tree

1. Strange transformations
   a. Extend your family tree back in time, and you might find that you are a direct descendant of George Washington, Charlemagne, Socrates, or King David. Extend the tree further back in time, though, and you will notice something strange. The way your ancestors look will start to change. It isn’t just that they dress differently or have different hair styles. Their faces and bodies will start to change. The change will be slow, but the cumulative effect will be undeniable. Indeed, trace your paternal family tree back two million years, and your ancestors will look like ape-ish men. Trace it back five million years, and your ancestors will look like mannish apes. Trace it back seven million years, and your ancestors will look positively ape-ish.
   i. These ape-ish creatures, by the way, wouldn’t have been monkeys. For one thing, we are much more closely related to chimps than to monkeys. Nor would the ape-ish creatures have been a chimps. Rather, they would have belonged to a species from which both we and chimps evolved. It would have therefore been of a different species than either humans or chimps. Scientists have given this species, about which we know little, a name: CHLCA, which stands for Chimp-Human Last Common Ancestor. Go back far in your family tree and you will find that a long interval of the tree would be populated by members of this species.
   b. A brief history of man, tracing back through our family tree. (The list I provide is somewhat speculative and there are lots of gaps in it.)
   i. Homo sapiens (the last 200 thousand years)
      (1) Apparently, Neanderthal man, which disappeared 30,000 years ago, and Homo sapiens shared a common ancestor, Homo erectus. It is not clear what became of the Neanderthals. Perhaps the Homo sapiens of that time (known as Cro-Magnon man) killed them off. Perhaps Neanderthals interbred with Homo sapiens.
   ii. Homo erectus (first appeared 2 million years ago)
   iii. Australopithecus (first appeared 4 million years ago)
   iv. Ardipithecus (proto-human; first appeared 5 million years ago)
   v. CHLCA, the Chimp-Human Last Common Ancestor (7 million years ago)
   vi. Go back further and you find:
      (1) Early mammals (small rodent-like creatures, about 200 million years ago)
         (a) If the dinosaurs hadn’t gotten wiped out by an asteroid, we might not have evolved beyond this stage. We humans are therefore the result of a cosmic accident!
      (2) Mammal-like reptiles
      (3) Reptiles
      (4) Amphibians
         (a) Tiktaalik (the “Darwin fish”) dates to 375 million years ago. See http://animal.discovery.com/videos/animal-armageddon-tiktaalik.html Notice that when Tiktaalik emerged from the water, it wasn’t onto barren land. There were already plants and also insects. Also, it isn’t clear that it emerged from salt water; it might instead have been from a river or marine estuary.
            (i) If it seems remarkable that fish could walk on their fins, consider the red-lipped batfish and frogfish: http://www.youtube.com/watch?v=X9inncLXAHg
            (ii) And instead of walking onto land, it is possible that the first fish flipped
onto it. Consider this video of leaping blennies:

http://www.youtube.com/watch?v=3Nh8bVDZGME

(5) Fish
(6) Eels
(7) Swimming worms
(8) Sponges
(9) Multi-celled organisms (530 million years ago; the Cambrian explosion.)
   (a) The difference between multi-celled organisms and colonies of organisms: In both cases, we find lots of cells of an organism stuck together, but in a multi-celled organism, the cells are specialized in their function (the way your cells are).
(10) Single-celled organisms
   (a) The first living things were presumably single-celled organisms. The problem with investigating the origin of life on earth is that single-celled micro-organisms rarely leave fossils behind.
      (i) Sometimes micro-organisms formed colonies which left behind physical structures. Stromatolites are the most dramatic example of this.
(11) First life: simple cells. (3.8 billion years ago)
   (a) At this point, we find the single-celled organism that was the common ancestor of all living things. Scientists have given this microbe a name: LUCA, which is an acronym meaning Last Universal Common Ancestor.
   (b) Remember that 4.6 billion years ago, earth would have been a molten mass, making life impossible. It is astonishing how quickly life arose on what would have been a sterile globe!

vii. For a wonderful animation of the evolution of man, see http://en.wikipedia.org/wiki/File:Ancestors.gif Realize that this animation begins with sponges. The family tree of man, however, goes back way beyond that, through single-celled micro-organisms, and all the way back to LUCA (the Last Common Universal Ancestor).

viii. A timeline for the evolution of plants and animals:

2. What is a species?
   a. The slow transformation of the ancestors in your family tree raises an interesting new issue involving the concept of a species. It is clear that you are a different species than, say, a lemur. It is also clear that, if what scientists tell us is true, you will find a lemur-looking animal in your family tree. Realize, too, that the change from lemur didn’t happen in a single generation: it wasn’t that a lemur gave birth to a human. Rather, the changes from generation to generation would have been almost imperceptible. And yet, allow such changes over a few million years, and the result is profound.
   b. People typically think that if two living organisms look alike (as two tigers do), they will be the same species, and if they look different (as a tiger and a cactus plant do), they will be of different species. This way of characterizing species is misleading, though.
      i. Two organisms can look quite different and still belong to the same species. Consider, for example, a 3 pound Chihuahua and a 120 pound wolfhound. They look very different—indeed, more different than a lion and tiger do. But they belong to the same species, Canis lupus familiaris.
      (1) By the way, despite their differences, all dog breeds share a same common ancestor:
the grey wolf. Not only that, but they shared this common ancestor only 15,000 years ago.

ii. Two organisms can look the same but belong to different species. Consider cacti and the plants known as euphors. Cacti were originally found in North and South America; euphors were originally found in Asia, Australia, and Africa. Both are desert-growing succulents. They can look very much alike: compare this barrel cactus (Ferocactus echidne) and this euphorb (Euphorbia fruticosa). Despite their similarity, they belong not only to different species but to different biological families.

(1) This similarity is the result of a phenomenon known as convergent evolution: two species independently hit on the same solution to a survival problem. In this case, the problem was surviving in the desert. Other examples of convergent evolution:
(a) Flight was “invented” independently at least four times, by insects, pterosaurs, birds, and bats.
(b) Whales and bats “invented” sonar independently.
(c) Eyes were independently “invented” as many as forty times.

c. The “acid test” for two organisms belonging to the same species: two organisms belong to the same species if they can successfully mate and have fertile offspring.

i. Applications of this definition:
(1) Horses and donkeys can successfully mate, but they are not of the same species, since the mule that would result from this mating wouldn’t be fertile.
(2) All dogs are of the same species, though, since a Chihuahua could mate with a wolfhound, and the “Wolf-huahua” that resulted would be fertile.

ii. If two organisms pass this test, they definitely belong to the same species. Realize, though, that if they don’t pass this test, they can still belong to the same species. Passing this test, in other words, is a sufficient but not a necessary condition for two organisms to belong to the same species.

(1) An eight-year-old boy and an eighty-year-old woman can’t mate with each other (or with any other human) and produce fertile offspring. This is because the boy hasn’t gone through puberty and the woman has gone through menopause. Nevertheless, they are both members of the species Homo sapiens.

iii. The above “acid test” is also limited in its applicability. Most significantly, it cannot be applied to bacteria and archaea, since they do not reproduce sexually. They instead reproduce by cloning themselves.

d. There is no hard-and-fast definition of “species.” Here is one common characterization: two things belong to the same species if they have a high degree of genetic similarity. (Notice that genetic similarity is different from physical similarity.)

3. How do new species arise?

a. According to creationists, new species arise when God creates them—an event, they will add, that happened only once in the history of the universe. This means that every member of a species would trace its family tree back to the members of that same species that God originally created. Thus, all of the ancestors of a modern horse were themselves horses.

b. According to advocates of evolution, new species arise all the time. This means that as you trace back your family tree, you will move through different species. Along similar lines, according to evolution theory, almost all the ancestors of a modern horse were not themselves horses.

c. To understand how new species can arise, we need to understand the concept of genetic drift. With the passage of time, the genetic makeup of the members of a species will slowly change, partly because of genetic mutations, partly because of environmental pressures (that determine
who lives and who dies, who mates and who does not).

i. The same thing happens in a language: current residents of England speak a different English than the residents of England did in Shakespeare’s time. This is an example of linguistic drift.

d. New species arise when some members of one species drift, genetically speaking, in a different direction than other members. As a result of this differential drifting, they become genetically dissimilar and thus cease to be members of the same species. There are many things that can cause differential genetic drifting:

i. Geographical separation. If members of a species are physically divided into two groups that are kept separate from each other, they can evolve into two species.

1. Continental drift can cause such physical separation.
   a. South America and Africa were once joined together and were presumably roamed by the same species. These continents have drifted apart, though, and as a result the species found in South America are different from the species found in Africa.
   b. This is why the animals in Australia, which has been “adrift” for millions of years, are so strange.
   c. Continental drift can also give rise to mountain ranges that divide the territory of a species into two separate regions, thereby giving rise to two distinct species.

2. A river might divide a region, and the animals on one side might not be able to cross it to mate with animals on the other side.

3. Climate change can separate members of a species into two groups.
   a. Climate change can result in changes in sea level, which can create new islands by flooding the region around what used to be hills. Many islands are homes to unusual species that can be found nowhere else. Rising sea level can also eliminate old isthmuses, and thereby prevent animals from moving from one landmass to another. This is part of the reason why the animals in North America differ from those in South America: the Isthmus of Panama was submerged for an extended period.
   b. Climate change can kill the middle of a forest, thereby dividing it into two widely separated forests. The animals in the two forests might evolve in different directions.

4. One species can evolve into two species even though members of the species continue to occupy the same “locality.” Thus, in London, England, underground tunnels were dug for the subway (or tube, as they call it). Some mosquitoes made their way into these tunnels and were subsequently isolated from the mosquitoes on the surface. As a result, they became a new species.

5. And even more interestingly, one species can evolve into two species even though they continue to live side by side.
   a. Suppose some members of a species group undergo a genetic change that makes them reluctant to mate with members of the species who have not undergone that change. (Although they could mate and produce fertile offspring, they simply don’t find each other sexually attractive.) Once two subgroups stop mating with each other, they will drift, genetically, in different directions, even though they live side by side.
   i. Notice that members of a species are typically biologically wired to be able to identify members of their own species. They might do this by sight or by
smell. They treat members of their own species differently than members of other species, and in particular, they find members of their own species sexually attractive.

(b) Likewise, suppose some members undergo a genetic change that shifts their breeding season. They will end up mating with only those who have undergone the same genetic change. (This can also happen to plants: if they change the time when they flower and release their pollen, they will fertilize and be fertilized only by plants that have undergone the same change.)

ii. Genetic drift is most likely to take place in small populations. This is because in big populations, any new genes that come along will be “drowned out” by mating with individuals that lack those genes. Thus, one wonderful way to start a new species is to take a few members of a species to an island.

e. The language analogy: if we take people who speak one language, divide them into two groups, and prevent members of one group from talking with members of the other, the groups will experience differential linguistic drift and will consequently end up speaking variants of the same language: think about the difference between American, British, and Australian English. If the separation continues, they will end up speaking different languages and will no longer be able to communicate with each other.

i. Along these lines, realize that Vulgar Latin, the language spoken in ancient Rome, subsequently evolved into the many different “Romance languages.” This happened because, after the Roman empire fell, groups of people in different geographical regions became linguistically isolated from each other. The languages that evolved include not only the well-known Spanish, Italian, Portuguese, and French, but other, more obscure languages. Here (according to Wikipedia) is how people say “She always closes the window before dining” in four of these less-well-known Romance languages:

(1) Aragonese: (Ella) tranca/zarra siempre la finestra antes de cenar.
(2) Aromanian: (Nâsa/ea) încildî/nkidi totna firida ninti di tsinâ.
(3) Asturian: (Ella) pieslla siempre la ventana/feniestra enantes de cenar.
(4) Bergamasque: (Lé) la sèra sèmper só la finestra prima de senâ.

4. We are left with the task of dividing our bloodline into different species. This immediately raises a transitivity problem. Consider three organisms, A, B, and C. If A is the same species as B, and B is the same species as C, then A and C must be of the same species, right? In other words, species- hood is transitive. This sounds perfectly plausible.

a. And yet, if we accept that species-hood is transitive, it means that if I am the same species as my parents (which I assuredly am, since they had me) and if my parents are the same species as their parents, then I am the same species as my grandparents. But by similar reasoning, they will be the same species as their grandparents—as, that is, my great-great-grandparents. But from this it follows, by transitivity, that I am the same species as my great-great-grandparents, which shouldn’t be surprising. The problem is that we can keep using this kind of transitivity logic indefinitely, with the end result that I am of the same species as the lemur-like creatures I find on my family tree 200-million years ago. Indeed, I am of the same species as LUCA. And that is simply absurd.

b. So, the process of sorting the individuals on my family tree into species is going to be messy. To a certain extent, we must draw lines in an arbitrary fashion, and wherever we draw lines will have the odd consequence of placing a child into a different species than his or her parents. We can get around this by declaring that the individuals in long stretches of our family tree don’t belong to a “real species”; we can instead designate them as belonging to a “transitional” species.
This device again seems arbitrary.

i. Paleontologists encounter this problem whenever they attempt to classify a new fossil find. If they find a fossil that is unlike any other, they can declare that they have found a new species. Once they have lots of fossils that are similar, though, the task becomes more difficult. And once they have enough fossils that those of one species “blend into” those of another, the task becomes harder still. Where to draw the line between species?

(1) When paleontologists assign fossils, they have lots of discretion. They stand before a cabinet of fossils, arranged chronologically. The fossils transform slightly from specimen to specimen. They pick one out and say, “that fossil defines the species.” [Van Andel, 325.] It becomes the “type specimen” for that fossil species. This is, of course, a highly subjective procedure.

(a) For more on the process of picking type specimens, see http://geology.about.com/od/paleontology/a/typespecs.htm
(b) For the type specimen of T. Rex, see http://www.carnegiemnh.org/exhibitions/paleolab/rex.html

(2) Suppose you were given the task of picking out the type specimen for Canis lupus, the species of which both gray wolves and dogs belong. (Canis lupus familiaris—aka, the dog—is taken to be a subspecies of Canis lupus.) Should you choose a “typical” gray wolf? a typical wolf-hound? A typical Chihuahua?

(3) And when you get done with this task, try picking out the type specimen for Homo sapiens—human beings, your own species.

(4) Likewise, how about the type specimen for a monarch butterfly, the bodies of which transform radically during their lives. Sometimes, biologists have mistakenly thought that animals at two different stages of life were two distinct species.

(5) Of course, with living things, we don’t have to rely on appearance to sort them into species; we can instead rely on DNA. But this leaves us with the question of which member of a species has the “typical” DNA. You might take this to represent the type specimen for humans.

(a) In the early 2000s, scientists revealed, for the first time, the human genome. The question is, which human’s DNA did they use? It turns out that they mixed the genomes of anonymous donors from Buffalo, New York. For more on this, see http://genome.cshlp.org/content/11/3/483.full or http://www.genome.gov/11006943

(b) Because it is difficult to identify species, it will be difficult to construct trees of life that map out the way species are connected. This is the problem we will turn our attention to later.
Chapter 13: Your Asexual Past

1. We have seen the problems that arise when you do your extended family tree. But there is one new problem that arises if you trace it back 2 billion years. The logic by which trees are made breaks down.
   a. In the family trees we have been doing so far, you list, above each individual, his or her two biological parents. These include the mother and father of any human, as well as the mother or father of the fish we ultimately find in your family tree, and the mother and father of the sponges that would fill your family tree, if you carried it back about 600 million years.[http://web.mit.edu/newsoffice/2009/nature-sponges-0204.html]
   i. But now, if you jump back to your ancestors of 2 billion years ago, we find that they were single-celled organisms that reproduced asexually. They reproduced, more precisely, by means of binary fusion: one cell would split into two. This means that if you pick a cell from 2 billion years ago and try to produce its family tree, you won’t be able to place two cells above it; rather, there will be the one cell from which it fissioned.
   ii. Thus, the family tree for the single-celled organisms in your past will be utterly unlike a family tree that involves sexual reproduction. It will be a straight line, with a “node” for each earlier cell. If we wanted to be complete, we could show the “other cell” that resulted from each cell fission, the way we can add siblings to family trees.

b. Issues arise when we attempt to join these two trees, the way we must if we wish to do your extended family tree.
   i. How do you join the straight lines of descent of asexual reproduction with the fusing lines of descent of sexual reproduction?
   ii. You can simply connect the straight lines of the family trees of asexually reproducing individuals to the individuals at the top of one of the “Ts” that would appear in the family tree of sexually reproducing individuals. But this requires that in one generation, two organisms that were formerly reproducing through fission not only figured out how to reproduce sexually but, having figured this out, discovered each other so they could produce sexually. It is quite a long shot that this would happen.
   iii. What is presumably more likely is that an organism that was capable of reproducing asexually gained the ability to reproduce sexually as well. It reproduced asexually, and its offspring found themselves in the same environment. These offspring on encountering each other, reproduced sexually.
      (1) Even today, we can find organisms that can reproduce both sexually and asexually. Aphids are one example. Through much of the year, they produce asexually, but when fall comes, they reproduce sexually.

2. Strategies for sexual reproduction.
   a. Plan A: External fertilization
      i. Random release of eggs and/or sperm into the environment. Trees, for example, release their pollen into the air.
         (1) This is, to be sure, a hit-or-miss way to reproduce.
      ii. An improvement on this is simultaneous release of eggs and sperm into the environment: both events happen at the same time.
         (1) This is what colonies of coral do. (Corals happen to be animals.) The releases are triggered by the phase of the moon.
      iii. Assisted fertilization involves the use of “third parties.”
         (1) Many plants rely on a “third party” to facilitate sexual reproduction. Honeybees play
this role. Different species of orchid rely on different animals to carry their pollen. These are examples of symbiotic relationships and the co-evolution of species.

(a) Flowering plants first evolved 160 million years ago. About 80 million years ago, they spread rapidly. This was made possible by the rise of insect pollinators. [Lane, Life Ascending, 121.]

iv. An improvement on this reproductive strategy is the cooperative laying of eggs and emission of sperm, like salmon do. Doing this requires a number of abilities:

1. The ability to move
2. The ability to recognize members of your own species
3. The ability to recognize which members of your species are of the opposite sex
4. The ability to recognize when females are fertile

(a) Cryptic ovulation by human females.

b. Plan B: Internal brooding.

i. One problem with external fertilization is that the fertilized eggs are left on their own. Many perish as a result. An improvement on this is for the parent to bring the fertilized egg back into their body. Although they fertilize their eggs externally, they brood them internally.

1. This is what many cichlid fish do. They are “maternal mouth brooders.” After the eggs have been laid and fertilized, the female takes them into her mouth. They stay there until they have “hatched” and grown a bit.
2. There are also paternal mouth brooders.

ii. A twist on this reproductive strategy is the male yellow seahorse. He has a brood pouch, as do most seahorses and pipefishes. It was thought that the male could internally fertilize eggs that the female put there, but in fact, it looks like the female releases her eggs in front of the male, who then releases his sperm. At that moment, he opens his brood pouch, which, in the process of opening, draws in the eggs and sperm. Thus, the eggs might or might not be internally fertilized: it depends on when the sperm and eggs unite. It all happens very fast: the brood pouch is open for only six seconds. See http://jeb.biologists.org/content/210/3/432.full.pdf

b. Plan C: Internal fertilization.

i. Instead of externally fertilizing eggs and then bringing them back into the mother’s or father’s body, why not just fertilize them while they are still in the parent’s body? This is what is known as internal (as opposed to external) fertilization. In internal fertilization, sperm is released into an organ where eggs are sure to be present.

ii. Within this “Plan C” for sexual reproduction, there are two sub-strategies:

1. Substrategy C1: Internal fertilization + external development
   (a) The creature with internally fertilized eggs lays those eggs and lets them develop externally
   (b) The dinosaurs did this and birds do this.

2. Substrategy C2: Internal fertilization + internal development
   (a) The creature lets the fertilized egg develop internally and gives birth to live offspring. This is what most mammals do.
      (i) An exception: monotremes (like the platypus) lay internally fertilized eggs.
      (ii) Internal fertilization is quite difficult for some mammalian species.
         1) Whales, for example, need to use prehensile penises, that have pretty much the same mobility as an elephant’s trunk.
         2) And while we are talking about sex among aquatic mammals, is
anything quite as beautiful as dolphin sex? Yes, there are videos: http://www.youtube.com/watch?v=RuH-t1q2hAc. Don’t blink, or you will miss it! This, by the way, is an example of ventro-ventral (face to face) sex, which is unusual in the animal world.

(iii) Mammals aren’t alone in giving birth to live offspring.


2) Sharks and rays do it as well. Not only that, but survival of the fittest begins, for sand tiger sharks, within the “womb”: the strongest unborn shark will eat the others: http://blogs.smithsonianmag.com/science/2013/04/baby-sand-tiger-sharks-devour-their-siblings-while-still-in-the-womb/.

(b) One unusual example of substrategy C2: The cichlid Copadichromis eucinostomus doesn’t wait for the egg to be fertilized. As soon as she lays it, she takes it into her mouth, where the male fertilizes it.[Zimmer, Parasite, 173.]

3. Internal fertilization is what we humans think of as real sex. This gives rise to the question, When did the first real sex take place?

a. The earliest known example of what must have been internal fertilization is the embryos inside specimens of Incisoscutum ritchiei, dating back approximately 380 million years ago. See http://www.sciencedaily.com/releases/2008/06/080606104814.htm. This seems like a pretty advanced version of internal fertilization, though, so “real sex” probably evolved before this.

4. Sexual reproduction raises lots of questions:

a. **Question: why reproduce sexually?**

   i. The disadvantages of sexual reproduction:

      (1) You only get to pass on (on average) half of your genes. By cloning yourself, you pass on all of them.

      (2) The time and trouble of finding a mate.

      (3) The possibility of venereal disease.

      (4) If you produce the ideal combination of genes through sexual reproduction, it will be diluted at the next mating.

      (5) Cloning is mathematically more efficient than sexual reproduction. In cloning, one cell becomes two: in sexual reproduction, two cells become one.

ii. But sexual reproduction is so common that it must have counterbalancing benefits!

   (1) Sexual organisms have two copies of each chromosome. This kind of redundancy is advantageous: if one copy of a chromosome is defective, the other copy can be used to provide the genetic information necessary for life processes. (For much the same reason, we have two lungs and two kidneys.)

      (a) But things are actually more complicated than this: there are asexually reproducing organisms that have two copies of each chromosome as well![Lane, Life Ascending, 125.]

   (2) Sexual reproduction provides greater genetic variety. You are slightly different than both of your parents. This is the key advantage biologists offer for sexual reproduction!

      (a) If many organisms of a species are nearly identical genetically (as they would be, if they resulted from cloning) and the environment changes, they could all perish. If the organisms of a species are genetically variable, though, and the environment
changes, there is a good chance that some of the variants will survive.
(b) In part as a result of their lack of genetic variety, clonal species tend not too last long.[Lane, Life Ascending, 132.]

b. Question: why not allow a single organism to engage in both sexual and asexual reproduction, and thereby obtain the advantages of both?
   i. This does happen in nature. Some species are “facultatively sexual.” They engage in sex occasionally, maybe every thirty generations.[Lane, Life Ascending, 132.]
      (1) Snails, lizards, and grasses switch between cloning and sexual reproduction, depending on circumstances.[Lane, Life Ascending, 133.]
      (2) Aphids reproduce asexually through the summer, but in late fall, they reproduce sexually.[Jablanka, 83.]
      (3) The water flea Daphnia reproduces asexually when times are good (when, that is, they are well-suited to their environment), but reproduce sexually when times are hard, to produce eggs that can survive the hard times.[Jablanka, 83.]
         (a) "This makes evolutionary sense. If an individual is doing well and its environment is not changing, asexual offspring, who have the same set of genes, will probably do very well too. So why change. If it ain't broke, don't fix it! Avoiding sexual reproduction will not only preserve a good set of genes, it will also double the rate of reproduction, because the is no need to produce males."[Jablanka, 83.]
      (4) The blood fluke Schistosoma mansoni is a parasite that uses snails and humans as hosts. It alternates between reproducing sexually in humans and asexually in snails.[Zimmer, Parasite, 20.]

   c. Question: if you are going to have sex, why just two sexes?
      i. Consider a new sex that could mate with either of two existing sexes. It would have twice the number of sexual partners, so we can imagine it would spread.[Lane, Power, Sex, and Suicide, 23.] "Two [sexes] is the worst of all possible worlds."[Lane, Power, Sex, and Suicide, 235.]
         (1) How do we count the number of sexes? On the basis of the possibility of gamete fusion.
      ii. Physarum polycephalum, a slime mold, has at least 13 sexes.[Lane, Power, Sex, and Suicide, 237.]
      iii. Schizophyllum commune, a mushroom with 28,000 different sexes. [Lane, Power, Sex, and Suicide, 236.]

   d. Question: if two sexes are a good thing, why doesn’t each individual have both sexes?
      i. The snail Bulinus truncatus is a hermaphrodite, with testes and ovaries. It can fertilize its own eggs and produce clones. But some also have a penis that can be used to mate with other snails. Each year, before the cool season, more of these snails have penises. (One parasitologist refers to this as penis season.[Zimmer, Parasite, 168.] ) Sexual reproduction allows mixing of genes, which in turn makes them more resistant to the attack of parasites when the weather gets warm again.
      ii. A side trip: the marine flatworm Pseudobiceros bedfordi is hermaphroditic. When one encounters another, they engage in “penis fencing”: each attempts to impregnate the other without getting pregnant itself. During penis fencing, they smear each other with sperm.
         (1) Oh, and did I mention that the flatworms in question have two penises?[Lane, Mitochondria, 232-223.]
      iii. And while we are on the topic of multiple penises: Each tapeworm segment has its own set
of female and male sexual organs. [Zimmer, Parasite, 137.] Tapeworms can be very long, though, thus making it possible for two tapeworms, all by themselves, to have a veritable orgy.

e. **Question: Why not be able to change sexes as circumstances require?**
   i. Why not, in particular, be able to undergo a sex change when circumstances change? This is what the bluehead wrasse fish can do. When the dominant male of a population dies or disappears, the largest female starts acting like a male, then changes coloration to look like a male, then the gonad transforms from an ovary into a testis. [Kirschner, Marc W. and John C. Gerhart, 94.]

5. The psychological consequences of the ability to reproduce sexually.
   a. Imagine an asexual you. You would be like you were as a child. You would have dramatically different interests and drives than you do.
   b. You are biologically programmed to seek sex and enjoy experiencing it. Is there an evolutionary explanation for this?
Chapter 14: The Tree of Life

1. The tree of life looks like a family tree, but instead of showing individuals, it shows species. Also, the “time arrow” on trees of life typically points upward.
   a. Examples of this, using Y-branching.
      i. The bottom of a Y represents the common ancestor of the species along the “arms” of the Y.
      ii. We and the neanderthals are two branches of a Y in the tree of life.
   b. The horizontal distance between branches of the tree will be roughly proportional to how genetically similar two species are.
   c. What does it look like when a species goes extinct?
      i. We will notice several levels of the tree at which there were mass extinctions, during which a bunch of branches simultaneously die out. The most recent of these was 65 million years ago, when the dinosaurs died off.
   d. Why will the tree be “flat-topped”? What species will we find in the top twigs of the tree?
   e. A complete tree of life would be very difficult to draw, since tens of millions of species now exist, and these represent only one percent of the species that have ever existed.

2. According to creationists, there is no tree of life. This is because species do not evolve into new species. Instead, there is a forest of life, with each tree in this forest representing a single species. Not only that, but the trees in this forest are themselves branchless, like bamboo. All these trees would have “taken root” at the moment of (or the days of) creation. Some would have “grown” until the present day. Many would have “stopped growing” in the past, when the species in question went extinct.
   a. Thus, the tree representing humans would have its root at creation and would still be growing; the tree representing T. rex would have its root at creation but would have stopped growing 65 million years ago. Indeed, because almost all the species ever to exist are now extinct, less than 1 percent of the trees in the “creationist forest of life” would still be “alive.”
      i. This raises, once again, the question of just how intelligent God or the intelligent designer could have been. Why create species only to have almost all of them go extinct?
      ii. This “forest of life” also leaves creationists with the problem of finding fossils for humans, horses, and whales dating back more than a few million years. None have been found!
         (1) Evolutionists have an easy explanation for this lack of fossils: Human-like beings evolved only about 7 million years ago, whale-like creatures evolved maybe 30 million years ago, and horses, in approximately their modern shape and size, evolved maybe 50 million years ago. We would therefore expect not to find their fossilized remains in geological strata more than 50 million years old—and we don’t!

3. Some examples of trees of life.
      i. An explanation: There are three domains of living things, bacteria, archaea, and eukaryotes.
         (1) The archaea and bacteria are single-celled micro-organisms.
            (a) Most people have heard of bacteria. They include E. coli, salmonella, staphylococcus, streptococcus, and spirochetes. (They do not include viruses, though.)
            (b) Archaea are less well known. They include the organisms known as extremophiles, which can live in very harsh environments, including environments that are salty, acidic, caustic, hot, or radioactive. Archaea are
placed in a different domain than bacteria because of important genetic
differences between them.

(2) The eukaryotes include all complex, multicelled organisms. Thus, we humans are
included among the eukaryotes. So are all other animals and all plants. The first
eukaryotes appeared 2 billion years ago. Before that, there were no complex,
multicelled organisms. There was life on earth, but it was pretty boring life!
(a) Notice that both bacteria and archaea descended from a common microbial
ancestor. Notice, too, that we are on the archea side of the family tree. Thus,
genetically speaking, we have more in common with “extreme” archaea than we
do with bacteria.

ii. A circular tree of life: [http://www.sciencemag.org/content/311/5765/1283/F2.large.jpg](http://www.sciencemag.org/content/311/5765/1283/F2.large.jpg)

(1) Notice how hard it is to find Homo sapiens on this tree. (We are on the right side,
third entry up from the bottom in the “pink” region.) Realize, too, that this is a
simplified tree of life!

4. Trees of life are misleading in a number of respects.
   a. The Y-branching technique suggests that one species can only divide into two. In fact, one node
      in the tree might have three or more branches coming from it. Suppose, for example, that
      members of one species were geographically separated into three groups and that afterwards,
      they evolved in different directions. Three new species would result.
   b. The Y-branching technique suggests that the species from which other species arose will itself
      cease to exist. This isn’t necessarily the case. A new species can branch off from a species that
      continues to exist.
   c. Bacteria can swap genes. This will cause our tree to have “lateral branches.”
   d. The most important thing that trees of life ignore is the fact that whether two things belong to the
      same species is not clear-cut. When geographical separation causes members of a species to
      evolve in different directions, there will be a point in time, early on, when they are still members
      of the same species: re-unite them and they will be able to reproduce successfully. There will be
      a point in time, later on, when they are clearly evolved into different species. And there will be
      an interval, in between these points, when they might or might not be able, if re-united, to
      reproduce successfully. To be perfectly accurate, our tree of life should reflect this phenomenon.